4.2. SPECIAL PROJECT: BOUNDARY WIND AND TEMPERATURE STUDY AT MLO, 1992-1993

Introduction

Perched on the north flank of the Hawaiian Mauna Loa volcano at an elevation of 3.4 km, MLO has been an important source of background atmospheric-aerosol and chemistry measurements for more than 35 years. The Mauna Loa volcano rises to an elevation of 4.17 km and stands as a major obstacle to the midPacific subtropical flow creating widely varying local wind regimes. At this latitude (19°N) the dominant climatological feature is the midNorth Pacific subtropical anticyclone centered to the southeast of Hawaii in winter and to the northeast in the summer months [*Blumenstock and Price*, 1974]. In the winter and spring period the synoptic scale wind field is predominately westerly at this latitude. During the summer months the flow is easterly on the southern side of the anticyclone. Superimposed on the large-scale synoptic flow is the diurnal up-down slope wind produced by diurnal heating and cooling of Mauna Loa. In the transition months the synoptic scale winds are significantly less important, and the local winds at MLO are determined in large measure by the regional scale thermal "breathing" of Mauna Loa. The resulting circulation, pressure, temperature, and moisture distributions are described in a series of studies and reports [*Price and Pales*, 1963; *Chin et al.*, 1971; *Mendonca*, 1969].

In 1984 an eruption and subsequent lava flow from fissures along the Mauna Loa east rift zone produced a lava flow to a point 2 km east of the observatory. This put a sense of urgency in efforts to construct a recently-approved lava barrier to the south of MLO to deflect any future flows that may originate above the observatory. From a micro-meteorological perspective, the concern at the time was that the lava barrier would selectively deflect the downslope winds or possibly create a separation of the low-level winds isolating MLO from the prevailing winds aloft. A stair-accessible tower was proposed to facilitate sampling above the influence of the lava barrier.

The lava barrier was constructed in January 1986, and in December the 40-m tower was erected. For the first time it was possible to install and maintain instrumentation well above the influence of the cluster of buildings that make up the observatory. Its predecessor, a 27-m tall antenna mast, was judged by most to be unsafe to climb due to its telescoping-type construction and age. In February 1987 an anemometer was installed on top of the 40-m tower. This was the second of two anemometers at the observatory, the first being at a height of 8.5 m, from which the station’s wind climatology was derived [for the latest update, see *Peterson and Rosson*, 1993]. Some months later when the measurements from both anemometers were compared, it was discovered that during periods of southerly winds, a distinct flow separation occurred in which the wind direction at the top of the tower was significantly different than that at the 8.5-m level. In some cases the difference was in excess of 90°. At such times the depth of the downslope flow is very shallow, less than 40-m deep. Using a captive balloon to obtain wind profiles in the lowest 0.5 km, *Mendonca* [1969] found the top of the nocturnal downslope flow to be at about 50 m in three soundings in September-November 1966. It is, therefore, reasonable to expect that a layer depth of less than 40 m could occur at other times of the year. Other than Mendonca's balloon study, there are few relevant observations of the temporal changes of the MLO boundary layer as a function of height.

The Bendix aerovane model no. 120 was used at MLO for the past 2 decades because of its durability, but at the price of a relatively high starting speed of 1-2 ms^{-1} and a long distance constant (63% recovery) of about 5 m [*Mazzarella*, 1972]. Starting thresholds in excess of 1 ms^{-1} and longer distance constants limited the response of the anemometer such that it was not a reliable sensor of wind fluctuations at heights less than 10 m where wind speeds were more often less than 3 ms^{-1}. A more sensitive anemometer was needed to depict changes that occur during the light wind characteristic of upslope-downslope transitions.

The objective of this report is to define the instruments, the installation process, and the procedure used to obtain a data set describing the first 40 m of the MLO boundary layer as a function of height and time. In addition, the wind and temperature profiles for the MLO Photochemical Experiment II (MLOPEX II) intensives from January 15, 1992, to February 15, 1992, April. 15, 1992, to May 15, 1992, and from July 15, 1992 to August. 15, 1992, are available from Internet by anonymous FTP @ftp.cmdl.noaa.gov. MLOPEX II is a continuation to an earlier field study and modeling of the photochemistry of the remote troposphere conducted at MLO in 1988 [*Ridley and Robinson*, 1993].

Instrumentation

During 1991 a large number of meteorological sensors were obtained from government surplus. Among these were sensitive cup anemometers (Climate model 011-4), wind vanes (Climate model 012-1), and aspirated air and dewpoint temperature sensors (Cambridge System model 137-MI-TC). The cup anemometers and air and dewpoint-temperature sensors needed modification before they could be used in the field. The anemometers were of a 1960s design in which the light from a small lamp was interrupted by a rotating chopper producing one pulse per revolution. A 16-slot chopper was installed yielding an event for approximately every 10 cm of wind as compared with an event for every 148 cm of wind with the single chopper setup. A frequency measurement with a resolution of 1 Hz yields a wind speed measurement to a resolution of about 0.25 ms^{-1}. The circuitry was removed from the air and dewpoint-temperature sensor, and the aspirated sun shield was used for a thermometer housing. Precision RTD platinum resistance thermometers (Logan model 4150) were used.

The anemometers were calibrated in the NCAR wind tunnel. The standard deviation of the calculated wind speed at 5 ms^{-1} was 0.18 ms^{-1} for the six anemometers. The accuracy of the wind tunnel was about 0.2 ms^{-1}. The wind vanes were mechanically aligned to an accuracy of $\pm 1°$. Additional uncertainty on the order of ±2-3° was added when the vanes were installed on the tower. All six thermometers were compared against a standard instrument and found to agree to within ±0.1°C.

Anemometers and thermometers were installed on the 40-m tower at approximately 3, 6, 10, 20, 29, and 38 m heights. A 1.2-m long arm was used to extend the anemometer and wind vane from the south side of the tower. Wind directions from 20 to 320° were relatively unaffected by the tower structure. The thermometers were also attached to this arm approximately 0.3 m from the tower. At each level, electronic modules were used to translate the signals from the sensors to a computer-compatible serial protocol (RS-485). A frequency-to-serial converter (MetraByte model M2602) was used to measure wind speed, and a bridge module (MetraByte model M2532) was used to measure the resistance changes that indicated wind direction. A RTD type 392 module (MetraByte model M1422) was used to interface the temperature probes. All modules were interrogated once a minute by a personal computer. Individual values were displayed on the computer monitor for quality assessment purposes. The observations were also stored on disk and sent to Boulder for further analysis. During the first 9 months that included MLOPEX II, January, April, and August intensifies, a telephone linkup between Boulder and MLO was used to transfer data on a daily schedule.

Discussion of Measurements

Case study April 23-29, 1992. Figure 4.6**.** displays the hourly-average wind profile in the first 40 m for the 7-day period April 23-29, 1992. The height is shown in meters on a logarithmic scale; time is in Hawaiian Standard Time (HST). This was a period of unusually steady winds from the west during which the MLOPEX observers noted considerable haze. Such windy periods are usually associated with migrating cyclones from higher latitudes and can represent periods of long-range transport from as far as the Asian continent. The large-scale pressure gradient will tend to overpower the local, thermally-driven upslope flow during such times. On April 23, a well-defined northerly upslope developed, but as the westerlies increased in intensity on subsequent days, the upslope consisted of a very slight veering of the wind during the daytime hours. As the strength of the westerly winds decreased on April 28-29, the winds shifted to a more northerly direction during the daytime hours.

The temperature profiles in Figures 4.7 and 4.8 show the temperature change as a function of height for April 23 and 25, respectively. The temperatures are hourly averages. On April 23 during the downslope flow (0000-0700 HST), the west-southwesterly winds were less than 10 ms^{-1} (Figure 4.6) and the temperature profiles showed very small changes in temperature until 0700 HST. Such temperature profiles are typical of the stable, nocturnal boundary layer. Note that the transition from westerly to northerly winds takes less than an hour (0900-1000 HST), and the temperature decreases by 3°C or more at all levels. This is due to the arrival of the cool, moist air from the Saddle region below MLO. With the return to a westerly flow at 1400 HST the sounding warms by about 2°C. After sunset the temperatures cool below 10 m and warm above that level to become nearly isothermal for the remainder of the day.

The situation is considerably different on April 25, when the effect of the thermally-driven upslope is masked by the dominant westerly flow from the west with no significant decrease in wind speed observed. The temperature profile (Figure 4.8) reflects the effect of a well-mixed boundary layer, as one would expect with winds greater than 10 ms^{-1}. The nocturnal sounding (0000-0600 HST) is isothermal with little change. Due to the mixing, all levels warm and cool adiabatically during the daytime, returning to a steady isothermal temperature between 8-9°C after sunset. (The 0.2-0.3°C warming at 30 m on all soundings indicates that this thermometer is biased to that degree.) In the steady nocturnal wind conditions of 0400 HST, April 25 (Figure 4.6) the Richardson number ($Ri = (g/\theta)\ (d\theta/dz)/dU/dz)^2$, $g = 9.8$ ms^{-2}) is calculated to be 0.0004. Thus with a logarithmic wind profile, $u^*(10\ m) = 0.83$ ms^{-1} ($u^* = kzdu/dz$, $k = 0.4$), and the z_o ($u(z) = u^*\ln(z/zo)/k$) is about 1 cm [*Kaimal and Finnigan*, 1994]. At 1200 HST the Richardson number is -0.003, $z_o = 0.02$ cm, and $u^* = 0.56$ ms^{-1}.

Climatology. The distribution of wind speed in four classes as a function of wind direction in 16 classes for the 10 and 38-m levels is shown in Figure 4.9. The wind roses include all of the hourly observations for the 2-year period in two classes, daytime and nighttime, since the diurnal forcing of the flow at MLO dominates the seasonal forcing. The times used to separate the daytime-nighttime regimes (0900 to 2000 HST, and 2100 to 0800 HST) were based on the most common time of transition from upslope to downslope. The northerly, upslope flow is clearly the dominant feature during the daytime at both levels while southerly, downslope winds are most predominant at night. During the daytime, the secondary maximum of stronger winds from the southeast and west directions are associated with periods when the large-scale pressure gradient dominates the upslope-downslope regime. The pressure gradient wind signature is also evident in the nighttime wind roses. The small percentage of northerly winds in the nighttime roses is due, in most part, to periods when the upslope flow persists for more than 12 hours, which usually occurs during the summer months. It is noteworthy

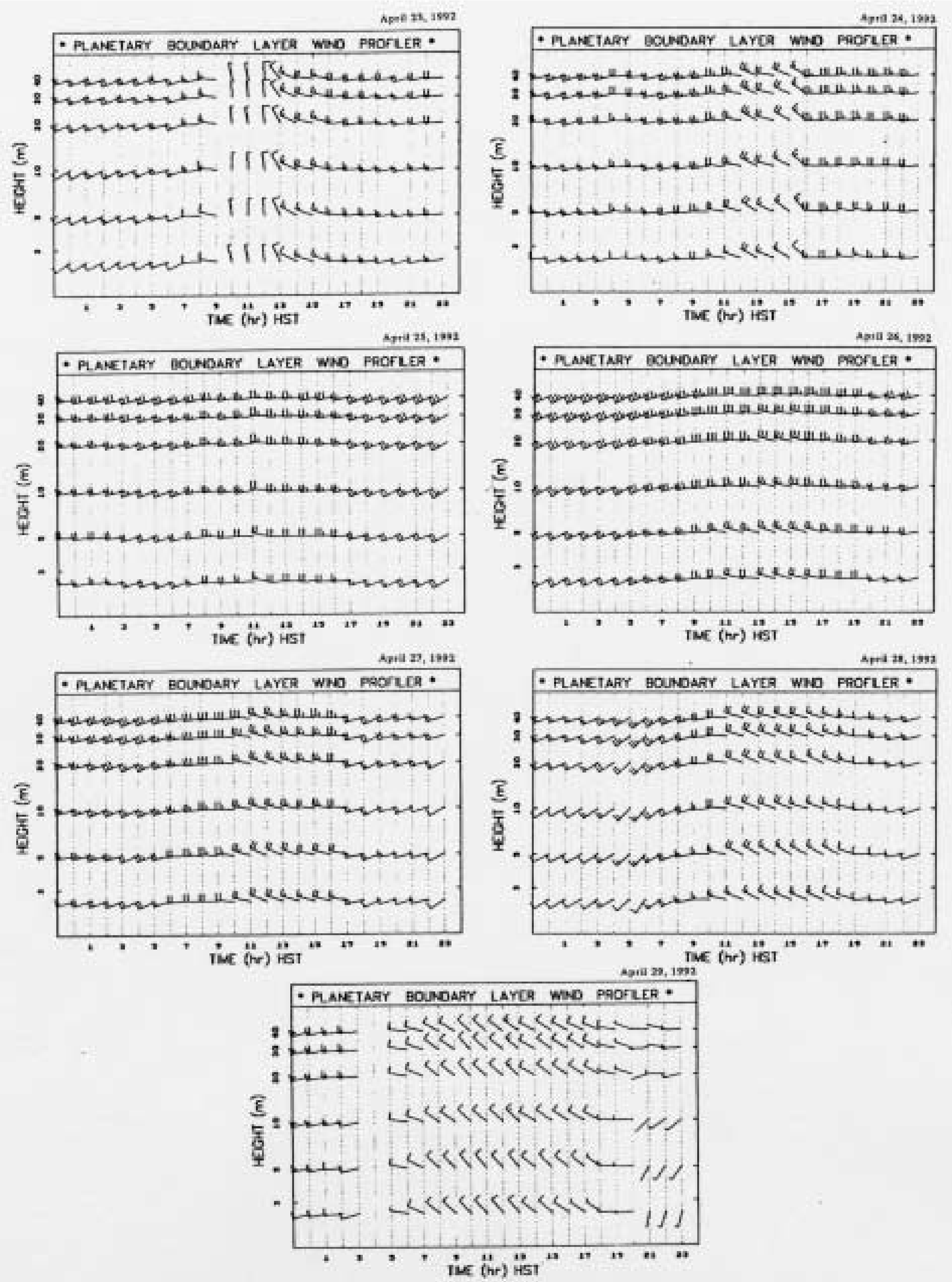

Fig. 4.6. Profiles of hourly average winds at MLO for April 23 through April 29, 1992. Individual wind barbs equal 10 knots.

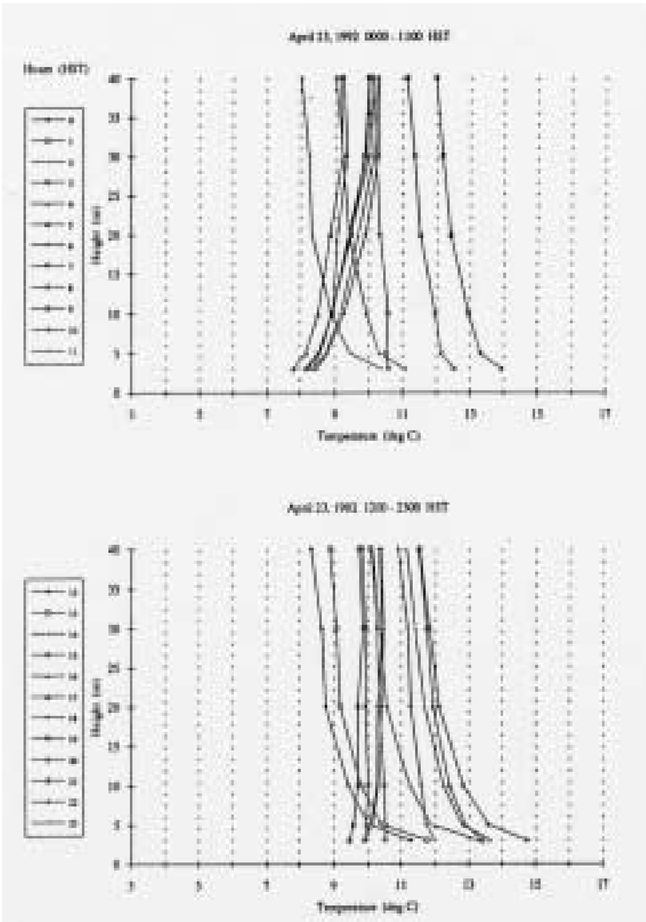

Fig. 4.7. Profiles of hourly average temperatures at MLO for April 23, 1992.

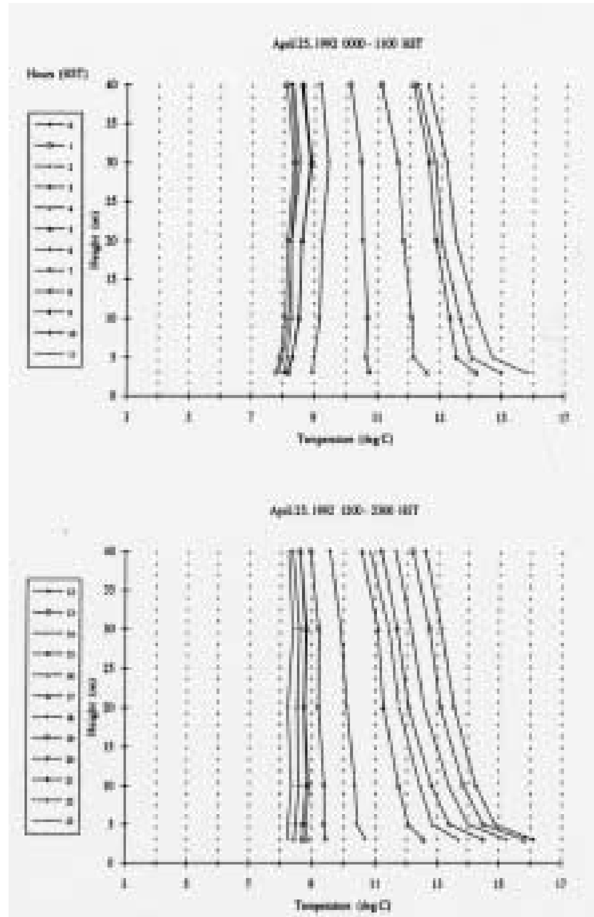

Fig. 4.8. Profiles of hourly average temperatures at MLO for April 25, 1992.

that while there is clearly a higher percentage of stronger winds at the 38-m level than at 10 m as would be expected, there is also a higher percentage of calm winds (WS<0.5 ms^{-1}) at the top of the tower as well.

As in Figure 4.9, the frequency of occurrence of wind speeds as a function of direction was calculated at the intervening four levels, and the results for all directions for both daytime and nighttime periods are shown in Table 4.8. The daytime flow is predominately upslope driven by the thermal heating of the mountain. Due to a well-mixed boundary layer, changes of the distribution of winds with height are small above the 3-m level. While there is a decrease in the percentage frequency in the three higher speed classes in the lowest 10 m, the changes are small above that level. The changes in the percent occurrence of winds less than 0.5 ms^{-1} (calm) decreases with height, except for a small increase at 38 m.

Reflecting the increase in stability in the boundary layer at night, the distribution of the wind speed with height takes on a different character from the daytime situation. While the percentage frequency of occur-rence of calm conditions and of winds greater than 5 ms^{-1} increase with height, the most common wind (0.5 to 5 ms^{-1} range) percentage of occurrence decreases with height. Considering winds from the south-southwest to west directions at speeds greater than 5 ms^{-1}, indication of the large-scale significant winds, there is a general increase in the percentage of occurrence with height. Interestingly, above 10 m the percentage occurrence at all wind speeds is relatively constant with height.

Summary

Based on this analysis, the measured gradients of temperature and wind are generally uniform above 10 m. Thus measurements at 10 m and near the top of the tower will describe the temperature and wind structure of the boundary layer over this range of heights. The 10-m level was selected as the reference level to remain consistent with WMO observational recommendations. A thermo- meter and anemometer are positioned at 38 m to characterize the flow on the upper half of the tower. Due to terrain irregularities it would be difficult to characterize the flow in any useful way with wind measurements below 3-5 m. However, temperature measurements at 2 m are important to depict the stability of the surface layer (Figure 4.8).

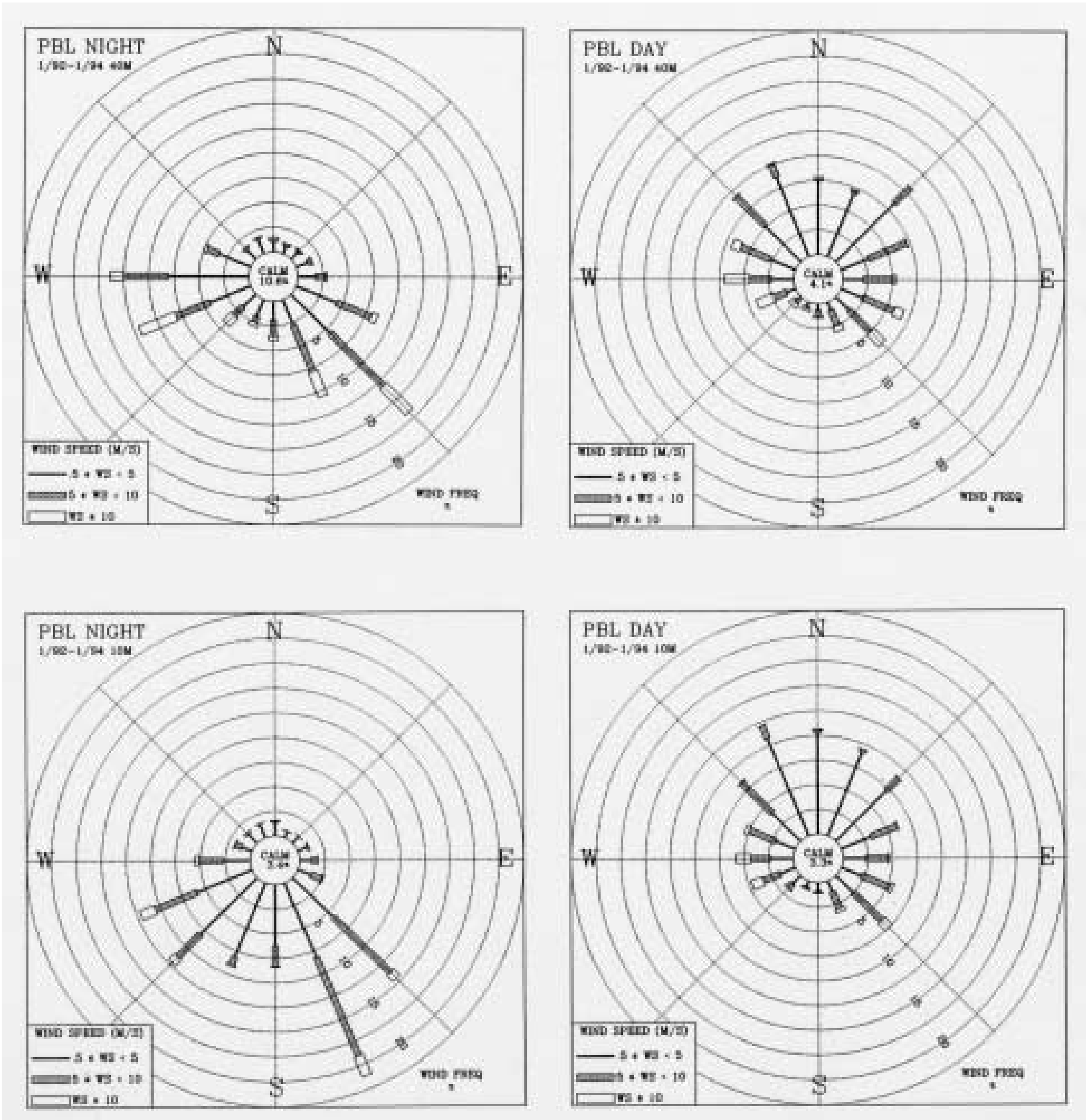

Fig. 4.9. Wind roses of the 10 m and 40 m level winds at MLO for night (left) and day (right) regimes. The distribution of resultant wind directions and speed are given in units of percent occurrence for the period January 1992 through January 1994. Wind speed is displayed as a function of direction in three classes.

TABLE 4.8. Percent Frequency of Occurrence of Wind Speed at Six Height Levels

Winds Speed ($m\ s^{-1}$)	Wind Height 3 m	6 m	10 m	20 m	29 m	38 m
Daytime conditions (0900 to 2000 HST)						
Calm	4.8	3.9	3.3	3.1	3.1	4.1
.5 to 5	73.8	67.1	60.8	54.6	53.5	53.6
5 to 10	19.4	24.8	30.1	33.5	33.5	32.1
10	2.0	4.1	5.8	8.8	9.9	10.3
Nighttime conditions (2100 to 0800 HST)						
Calm	4.1	3.1	3.4	4.8	7.5	10.6
.5 to 5	70.5	62.8	54.9	47.9	44.3	42.1
5 to 10	23.2	29.8	35.2	36.4	34.2	32.1
10	2.2	4.3	6.5	10.8	14.0	15.2
5*	5.2	7.9	9.0	13.0	13.9	13.5

*Direction limited to west through west southwest.